Basic Research as an Integral Component of a Self-reliant Base of Science and Technology

Its Role, Relevance, Support, Areas of Thrust

M G K MENON

Presidential address

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FOCAL THEME

BASIC RESEARCH AS AN INTEGRAL COMPONENT OF A SELF-RELIANT BASE OF SCIENCE AND TECHNOLOGY

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by
M.G.K. Menon

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I am deeply grateful to the Indian Science Congress Association for the honour they have done me in electing me as President for the year 1981-82.

DEDICATION

This address is dedicated to two great Indian scientists who have been past Presidents of the Indian Science Congress: Professor Sir C.V. Raman and Dr. Homi Bhabha who presided over the sessions in 1929 and 1951 respectively; and to two other great scientists, Prof. Cecil Powell and Lord Blackett. Prof. Powell had visited India many times and addressed the Indian Science Congress at its Agra (1956) session. Lord Blackett had also visited India many times, the first time being for the New Delhi (1947) session of the Indian Science Congress presided over by Jawaharlal Nehru. I had the great privilege of knowing each of them personally and closely. They had very different backgrounds, personalities, and experiences, but each reflected excellence, and the distilled essence of science and scientific method, in all facets of their lives. It is from them that I have learnt a large part of the history, philosophy and method of science; and a great deal of what I have to say today will reflect this.

FOCAL THEME

I have chosen, as the focal theme for this Session of the Science Congress, the subject of "Basic Research as an Integral Component of a Self-reliant Base of Science and Technology", covering aspects relating to its role, relevance, support and areas of thrust. I selected this theme intentionally, because for some time now, I have felt that, in response to meeting needs arising from the immediate and serious problems that we face as a society and a nation, understanding relating to the importance of basic science and research on fundamental aspects, and support for it, is gradually diminishing.

We are well aware of the many conflicting demands on our national economy. There is the already large population, which is continuing to grow, and there are the obvious requirements of food and nutrition, health, housing, clothing and education and providing employment that have to be met. We are now facing major problems in the area of energy which was the subject of the Presidential address of Prof. A.K. Saha at the 67th (Jadavpur) Session of the Indian Science Congress. In the current world situation, there are the growing and grim demands of national security. There are then the

requirements of industrialization and of providing gainful employment. From time to time we are faced with natural calamities like floods, droughts, cyclones and the like, which constitute sudden and unexpected stresses on the national economy. All of these demand significant allocations from the national exchequer and call for immediate attention and solution. Indeed at the 1947 Session of the Indian Science Congress held at Delhi, the President of the Indian Science Congress Jawaharlal Nehru said "For a hungry man or a hungry woman, truth has little meaning. He wants food. And India is a hungry, starving country, and to talk of Truth and God, and even of many of the fine things of life, to the millions who are starving is a mockery. We have to find food for them, clothing, housing, education, health and so on, all the absolute necessities of life that every human man should possess. So science must think in terms of the few hundred million persons in India." In the face of this, it would not be unusual for the decision makers to regard basic research as a non-priority item. But Jawaharlal Nehru, in spite of the connotation that might be put on what I have just quoted, supported science in the fullest measure; and as scientists we have cause to be deeply grateful to him for his abiding interest in science, and his vision and wisdom in creating the powerful base that we possess today; he understood fully that science is not cake but the bread and the staff of life of our type of civilization.

Having stated what is obvious, that we face immediate major problems that confront society on a day-to-day basis, I would ask whether these urgent priority tasks in the sectors of food, energy, health, employment and proper utilization of natural resources etc. can be dealt with without recourse to a self-reliant base of science and technology in the country. And the answer is a definite NO. To me it is clear that we are allowing problems of the present and immediate to overwhelm us, to such an extent that the much smaller effort required to ensure that, in the long run, we can significantly ride above such situations, is being lost sight of.

The purpose of my address is to point out that there are certain philosophical, cultural and intellectual aspects of basic research that are not well appreciated, but which underpin in an essential manner the very concept of self-reliance. And for basic research to flourish it needs an appropriate environment and climate as much as financial support.

S AND T COMPONENT OF THE SIXTH PLAN

Last year, a major exercise was carried out to formulate the Sixth Five Year Plan of the country for the period 1980-85. I had the privilege of chairing a Working Group constituted by the Planning Commission to prepare the draft chapter on science and technology for the plan document. In starting on

this task, I went back to the Scientific Policy Resolution adopted by the Government on 4 March 1958. (I have, for convenience of readers, reproduced this resolution in full, as an appendix to the written text of this address.) This was a most remarkable document adopted by this country, through the visionary foresight of Jawaharlal Nehru. In its operative part, it says:

> "Science has developed at an ever-increasing pace since the beginning of the century, so that the gap between the advanced and backward countries has widened more and more. It is only by adopting the most vigorous measures and by putting forward our utmost effort into the development of science that we can bridge the gap. It is an inherent obligation of a great country like India with its traditions of scholarship and original thinking and its great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today."

Indeed, with the great support given by Jawaharlal Nehru from the time of Independence, vigorous measures were taken for the development of science through larger financial allocations; from Rs. 20 crores for Plan and Non-Plan of the First Five Year Plan (1951-56), this allocation has gone up to Rs. 3367 crores in the Sixth Plan (1980-85). There has been a significant increase in the number of universities, institutes of technology, agricultural universities; a large number of National Laboratories have been set up under various agencies covering the entire spectrum of science, engineering, technology and medicine. There has been widespread application of science to national problems in the areas of agriculture, health, industry, energy, communications and so on; impressive returns have been obtained in many cases. There is today a significant infrastructure for science and technology in the country; a stock of scientific and technical manpower which also is large at first sight, being estimated at 2.5 million; and many major achievements in the form of accomplishments of tasks that have been clearly assigned. Indian scientists are well recognized and regarded on an international plane.

In spite of all this, taking note of the spirit of the Scientific Policy Resolution, which I had just quoted in its operative part, the unambiguous and clearly laid down policy of attaining self-reliance and the large and important position that India has in the community of nations, the working group asked itself: "how far have we gone bridging the gap and in participating fully in the march of science"; and it came to the conclusion that "while significant advances have taken place on the science and technology front in India over the past three decades, the gap between what obtains in the country and in other advanced countries, in terms of infrastructure and

capabilities, has significantly widened... There are many gaps in important fields and in the ranks of leadership and in excellence."

THE NURTURING OF SCIENCE

I am personally of the view which is shared by a large number of my distinguished colleagues in the scientific community of this country, with whom I have had extensive discussions, that the concept of excellence is being lost, that centres of excellence in the country are finding it difficult to survive because of lack of appreciation concerning issues of an administrative and financial nature and what might be referred to as personnel and labour aspects, particularly in terms of the laws of the land and the attitudes taken by our judiciary; our brilliant students have very few positions for training and further research at outstanding centres. Our educational institutions which have the responsibility for generating our scientific manpower have been sadly neglected in terms of support, even on a selective basis. Those who would potentially be the great scientists of the future are drifting to professions other than science, or are moving abroad where better opportunities exist. The Working Group on Science and Technology for the Sixth Plan has expressed its deep concern over all of these issues. There is, therefore, need for a much wider appreciation and debate on these issues, since they are indeed fundamental and serious.

I have asked myself: "Under what auspices could questions of this type be publicly posed, leading to a greater debate on the problems and solutions". In terms of scientific bodies, there is the Science Advisory Committee to the Cabinet (SACC), the creation of which the Prime Minister announced at the last Indian Science Congress session at Varanasi; SACC has met several times over the past year, and has concerned itself with some of these basic issues. There are the academies of science and other professional societies. And then there is the Indian Science Congress Association which covers the broadest spectrum of scientific disciplines and whose membership today stands close to 7400. I believe that the issues we are considering are so important that they must be debated in all these forums.

I have noticed that the Indian Science Congress, in its sessions for quite some time now, has discussed many areas of national life where science has relevance and finds significant application. This is important. I also believe that the approach of selecting one broad area of national relevance and importance as a focal theme, on which scientists from different areas of science can focus their attention will lead to coordinated, interdisciplinary and integrated efforts. In all of this there is the basic assumption that the scientific base is strong, and itself needs no attention; and therefore our attention should

be profitably concentrated on "applications of science". If, however, the base of science in the country is weak or unsound or not getting the support and climate that it needs for its own growth and development then science as a force for development will obviously not be very effective. It is this question to which I wish to address myself: "how is science itself to be nurtured and developed in a manner in which it can be a successful component of development?"

It will be seen that the focal theme essentially covers three components: the concept of a base of science and technology; the concept of self-reliance; and within this framework the role and relevance of basic research; other aspects that we will consider are support and areas of thrust in respect of basic research.

SCIENCE AND TECHNOLOGY: GENERAL ASPECTS

The world of today is largely the product of developments that have taken place in the field of science and technology; no doubt other social, cultural and economic aspects have influenced and made possible the self-sustaining exponential growth of science and technology that has taken place. These developments have occurred over the past few hundreds of years since the scientific and industrial revolutions took place. It must be remembered that science did grow but declined in many earlier civilizations, and did not attain the present self-sustaining character that we see around. The present developments were nucleated in what are the great industrial centres of the world today; as a result these areas were able to make rapid progress in the material sense, to become the highly developed countries. 97% of the world's research and development is carried out in these developed countries and only 3% in the less developed countries.

At this point I am reminded of what Cecil Powell said when he was arguing in the early 1950s for support for basic research in Europe. At that time the United States was vigorously moving into the field of high energy elementary particle physics, and European physicists were trying to obtain support for a common European accelerator and high energy physics which today exists as CERN (European Council for Nuclear Research). Cecil Powell then said: "In the long run, it is most painful, and very expensive, to have only a derivative culture and not one's own, with all that it implies in independence in thought, self-confidence and technical mastery. If we left the development of science in the world to the free play of economic factors alone, there would inevitably result a most undesirable concentration of science and scientists in too few centres, those rich in science becoming even richer, and those poor, relatively poorer". This was as between Europe and America then. The disparity that

exists is infinitely greater between the developing and developed countries. The UN Conference on Science & Technology for Development was held in Vienna in August 1979 precisely to seek ways to reduce this disparity, so as to lead to a New International Economic Order.

The spectacular, and highly visible, material developments that have taken place as a result of advances in science and the rapid succession of technological innovations in the areas of industry, agriculture, medicine, transportation, communications, energy etc. are there for all to see. High speed jet engines and wide-bodied aircraft have resulted in mass transportation which has made the world a small place physically; the advent of the Space Age and of geo-stationary satellites, and the developments of modern electronic techniques have resulted in worldwide radio and TV broadcasting and telecommunications, which have made the earth a small place in terms of communications, transmittal of ideas and human expectations; advances in medical sciences, with modern antibiotics and other miracle drugs, as also our greatly increased basic understanding of biology at the molecular and cellular levels have had a profound impact on world population (with reduction in death rate and rapid rise in population), treatment of disease and the promise of an unending chain of new possibilities; modern high-yielding varieties have enabled food production to keep pace in some sense with the expanding populations; the developments in modern electronic techniques have made it an all-pervasive technology, affecting entertainment, industry, defence, communications, space technology, computer and information sciences and the like. All of this has resulted in rising expectations the world over, and a feeling of euphoria that science and technology is a magic wand to bring about development. The point that needs to be emphasized is that *science and technology is not a magic wand.* We must explode the myth that science is a great external solver of all problems. Lord Blackett in the first Jawaharlal Nehru Memorial Lecture given in 1967 had said: "Science is no Magic Wand to wave over a poor country to make it a rich one".

We have also to remember that science and technology should not be looked upon as a separate entity to be separately accountable for development. In this connection, Casimir has remarked "Science and Technology *cannot* be applied to development. Science and technology are an essential part of development. One does not apply one's lungs to respiration, nor one's heart to the circulation of blood nor one's legs to walking. If we regard science and technology as a crutch, it will at best provide a halting gait. If we regard them as a transplanted heart, they will sooner or later be rejected

by the receiver". Science, and technology which is based on a basic understanding (in contrast to pure implementation of a well-defined set of technical tasks) cannot be imported nor be regarded as an external entity. It has to be an integral part of all our activities.

SELF-RELIANCE

We have to recognize that India is a large country of sub-continental dimensions, with a population close to 700 million. The very size of our country, and the diversity and complexity of the problems we encounter, which are quite different from those of smaller developing countries, demand self-reliance. The Prime Minister, Mrs Indira Gandhi, has remarked: "Self-reliance must be at the very heart of S&T planning. There can be no other strategy for a country of our size and endowments. While we all readily pay obeisance to this concept, there are too many and too frequent lapses. Considerations like security, the time factor, performance guarantee and costs often compel us to buy advanced technology from the international market. But in the ultimate analysis, neither true defence nor true development can be bought or borrowed. We have to grow them ourselves". She has further said: "Self-reliance does not mean making everything ourselves but acquiring the capacity to do so when things come to a head".

The pathway to self-reliance is not to set out to rediscover independently what has already been discovered, nor to invent what has already been invented. It implies the ability to analyse problems, and to define tasks and objectives; to obtain information/know-how etc. which is needed from wherever it is available, but on a specific basis; to have self-confidence to develop whatever needs to be developed; and most important, the ability to start from a base which may be a mix of indigenous and imported know-how, to move into the future on an internationally contemporary basis through innovation and original thinking. Self-reliance should also not be confused with self-sufficiency. Self-reliance demands a national commitment and political will; and involves many facets such as technology policy; management and technical skills etc. But clearly a crucial element of self-reliance, in a world whose economy and life styles are dominated by scientific and technological advances, has to be a self-reliant base of S&T. And this base cannot be built without at the same time doing significant basic research; for that is the only way to generate basic understanding which is not restricted to specific knowledge in an area, but provides the ability to attack and solve problems over a wide spectrum; and it is this ability that basic research more than anything else develops to the highest degree. Aspects to basic research and the qualities that it demands are dealt with a little later.

THE INNOVATION CHAIN

I would now like to consider the place of science and technology within the overall framework of the productive sector. It was Lord Blackett who, in the first Jawaharlal Nehru Memorial Lecture, outlined the importance of ensuring the integrity of various links in what he referred to as the 'innovation chain', if investments at various points of the chain are to be fruitful. 'Innovation chain' is a term that has been used to signify the whole process from fundamental research (which is concerned with the discovery of new facts and the understanding of nature and hitherto unknown principles), through applied research (which involves definite practical objectives), to the building of prototypes in laboratories, to the development of a small number of items in batches on a pilot plant basis to test out production techniques (and analogous pilot plant operation for testing the feasibility and economics of process techniques), to devising processes to suit available skills and equipment and the use of items that are most easily and cheaply available, to the final emergence of marketable products or of services; in the fields of agriculture and medicine, the intermediate steps would be of field trials and liaison with the producers and users of the products. It is important to recognize that scientific research represents only the first few steps in this long and expensive chain. A high level of research and development *alone* is not sufficient to ensure successful innovation; the industrial and commercial elements of the chain are equally vital. Actually, research and development claims generally only a small part of the total costs of successful innovation. On the average, it is estimated that about 5-10% of the total launching cost of a successful new product goes into the research and development leading up to the basic innovation; and about 10-20% goes into the engineering development and design of the project. The remaining 70-85% is needed for the tooling costs for first production, and for the initial manufacturing and marketing expenses.

Thus, the British textile material "Terylene" was invented in a research laboratory running at less than $ 60,000 a year. When Imperial Chemical Industries obtained the UK commercial rights for this invention, it then spent the equivalent of around $ 11 million on pilot plant development; and for the first major commercial production, the new plant cost around $ 40 million. The economic factors involved in the various elements of this innovation chain have to be well understood if the investments on research and development are to be profitable, and not lead to frustration.

If on the basis of careful perspective planning, one can define end-requirements well in advance, particularly in the major economic sectors, then resources—human and financial—can be deployed wisely and in time on

research, development and other aspects, with the clear-cut expectation that investments will be forthcoming in the later elements of the innovation chain in the productive sector, to make use of the scientific effort that has gone before. In the absence of such perspective planning, and linkages between the productive sector and the R&D sector, as also policies arising from pressures relating to immediacy of requirements which have enabled technology to come in easily, the investments on science and technology, particularly on applied R&D, have often appeared to be unproductive, though the tasks defined for them had been accomplished; and this has been a frustrating experience for scientists. This has also led to the question that the scientific community is very often asked: "So much money has been allocated for science; what have we got in return?" It is essential to realize that returns will be forthcoming only if adequate investments are made in the different downstream steps of the innovation chain, and time elements that are relevant are kept in mind; we have to remember that long gestation periods are involved in the fructification of S&T efforts. And applied R&D, design and development work should not be initiated in areas where no chance of fruition exists, whatever be the reason.

There is often a tendency to use the wide umbrella term 'science and technology' under which many different facets are subsumed. This has resulted in a great deal of confusion in defining investments, efforts etc. that relate to the different components of Science and Technology. We have already seen that the largest resources—human and financial—in the productive sector, whether it be in agriculture, industry, transportation etc., have to be in the later stages of the innovation chain. Though these productive activities are based on science and technology, and they absorb the larger part of the output of trained technical personnel emerging from the educational institutions, they cannot be, (and are not), treated as the S&T sector. The latter is concerned with research (pure and applied), design and development. As already stated, applied research and development can fructify only when there are clear-cut end-objectives and needs, and appropriate guarantees and linkages to ensure utilization through investment in the productive sector. The largest part of the budget of the S&T sector in the country has so far gone into the areas of applied research and development, whether they be in the areas of atomic energy, space science and technology, defence or through the Councils dealing with Scientific and Industrial Research, Agricultural Research or Medical Research. In each of these areas, there is only a relatively small amount which goes into basic research. However, because of the overall allocations for science and technology, under which umbrella title basic research is also subsumed, it is generally assumed that it is also well looked after. But this has not been the case in real terms, and particularly in the

context of the headlong advances that science and technology have been making and the completely new areas that are being opened out on an international plane.

A RESTATEMENT OF THE BACKGROUND

In what I have said up to now I have covered several different facets of the scenario that a policy maker in the field of science and technology is confronted with. It would be good if I attempted at this stage to draw together the threads of my discussion into some simple statements. First, Indian planning since Independence has sought to work towards the objective of self-reliance; and this is the banner under which we have been marching all these years. Whilst we have many individual achievements in science and technology to our credit, and today we produce a very significant part of all that we need for daily life within the country, yet we must admit that we still have a long way to go in attaining true self-reliance. In a world that has been fashioned by science and technology, and of which we are a part, it is quite clear that national self-reliance implies a self-reliant base of science and technology. For science and technology to fructify in terms of meaningful national development, it has to be ensured, on the one hand, that there are investments downstream, to ensure that know-how that is generated through applied research and development is transformed in a productive manner for the benefit of society; and on the other, that where large investments are involved in the science and technology sector, as is the case of applied research and development, this is done only in areas where, on the basis of long range planning, it is clear that there are needs and users. We are, of course, aware of many instances where users project their needs much too late for national S&T to respond or make any useful contribution; and usually these instances relate to large projects. This should not be permitted.

The quality of excellence in all that we do can come about only if support is given to sectors such as basic research in the same manner as in sectors such as exports where the highest international standards alone will ensure competitiveness. I shall now pursue in the remaining part of my talk, the role and relevance of basic research in promoting innovation and excellence.

BASIC RESEARCH: ITS ROLE AND RELEVANCE

In January 1966, in the last speech that he gave in his life, Homi Bhabha, addressing the International Council of Scientific Unions in Bombay remarked:

> "What the developed countries have and the underdeveloped lack is modern science and an economy based on modern technology. The

problem of developing the underdeveloped countries is therefore the problem of establishing modern science in them and transforming their economy to one based on modern science and technology. An important question which we must consider is whether it is possible to transform the economy of a country to one based on modern technology developed elsewhere without at the same time establishing modern science in the country as a live and vital force. If the answer to this important question is in the negative—and I believe our experience will show that it is—then the *problem of establishing science as a live and vital force in society is an inseparable part of the problem of transforming an industrially underdeveloped to a developed country.*"

At this point, let us consider the important question Bhabha raised: Is it possible to transform the economy of an industrially underdeveloped country to one based on modern technology developed elsewhere without at the same time establishing modern science in the country as a live and vital force? Bhabha answered it in unequivocal terms on the basis of his experience in India for quarter of a century.

Bhabha had returned to India with an internationally established reputation as a theoretical physicist of the first order. Working during the years of the Second World War at the Indian Institute of Science, this outstanding theoretical physicist began thinking of the need to establish modern science in India, of the needs of energy for economic development, the great potential that nuclear power was likely to offer in this regard within a couple of decades, and the enormous possibilities of leapfrogging in the process of development through modern sophisticated techniques. He did not, however, approach these possibilities in the manner in which foreign collaborations are normally embarked upon. He first proceeded to build a base of fundamental research by setting up the Tata Institute of Fundamental Research; he did this because he had become aware of the shortcomings of science in India in some of the modern areas such as nuclear physics, high energy physics and so on, and felt that in these areas where so much fundamental and exciting work was going on, India should not be left out. He was also clear that in setting up such an institution, it would be necessary to introduce modern concepts of administration and research management, which would lead to an atmosphere and environment conducive to its being a pace-setter for the growth of science and self-confidence, and be the base from which major ventures could be undertaken. Lord Penney writing on Homi Bhabha in the Biographical Memoirs of Royal Society has stated, "In the 21 years since the Institute was inaugurated in Bombay to Bhabha's death in 1966, the Tata Institute of Fundamental Research has grown to be one of the

finest research institutes in the world". In the letter that he wrote to the Sir Dorab Trust outlining the proposal for setting up the Tata Institute of Fundamental Research, Homi Bhabha showed that he was also clear about the long-range fall-out and the imperatives of self-reliance in a strategic area. In a visionary and prophetic sentence he remarked "Moreover, when nuclear energy has been successfully applied for power production, in say a couple of decades from now, India will not look abroad for its experts but will find them ready at hand".

Since Bhabha conceived of the Tata Institute of Fundamental Research, many new areas have developed right at the frontiers of science, for example in modern biology, with unambiguous indications of relevance, applications and growth. It is clear that we need to grow many more such institutions, and particularly in close coupling with the educational system.

Then Bhabha went on to develop the atomic energy programme; and he selected physicists, chemists, engineers and biologists who would work not on a purely imitative basis or by reverse engineering, but on the basis of an understanding of the basic elements in their areas, whether it related to materials, structures, heat transport, spectroscopy, chemical reactions and so on. It is this strength of basic understanding which characterizes the Indian nuclear programme, and which has enabled it, in spite of many hurdles encountered more recently in the area of international cooperation, to stand on its own feet. At the dedication of the new buildings of the Tata Institute of Fundamental Research in January 1962 by Jawaharlal Nehru, Bhabha had remarked: "The support of such (basic) research and, of an institution where such research can be carried out effectively, is of great importance to society for two reasons. First of all, and paradoxically, it has an immediate use, in that it helps to train and develop, in a manner in which no other mental discipline can, young men of the highest intellectual calibre in a society, into people who can think about and analyse problems with a freshness of outlook and originality which is not generally found. Such men are of the greatest value to society, as experience in the last war showed; for many of the applications of science, which were crucial to the outcome of the war, were developed by men who, before the war, were devoting their time to the pursuit of scientific knowledge for its own sake. Radar and atomic energy are two examples of fields in which a vast body of established basic knowledge was developed into technology of immense practical importance, largely through the application in war time of the efforts of those who might be called 'pure' scientists." Bhabha further said: "It is not an exaggeration to say that this Institute was the cradle of our atomic energy programme".

I have just conveyed to you what one of our great scientists Homi Bhabha, who made his reputation by accomplishing basic research of the highest quality, and who was responsible for promoting much else in national development in the fields of atomic energy and electronics, felt about the importance of basic research. I fully concur with all that he had to say.

ASPECTS OF PURE AND APPLIED RESEARCH AND LINKAGES BETWEEN VARIOUS CONCERNED INSTITUTIONS

I would now like to put down for clarity certain specific aspects concerning various forms of research activity, and their respective roles and relevance. Research is often categorized as pure research and applied research. The fundamental difference lies in the motivation. The motivation in the case of pure research is the desire to know something, whereas in the case of applied research it is the desire to do something. The words pure, fundamental or basic are often used synonymously.

Basic research is concerned with discovery of new knowledge and with increasing our understanding of natural phenomena. It ultimately leads to a clearer and sharper definition of the laws which govern nature. Basic research is not directed towards the solution of immediate practical problems. Basic research, by definition, is at the frontiers of our knowledge; and the quality of work and achievements have to be judged by the entire international scientific community. Quite clearly those who would accomplish such research have to possess capabilities necessary for work at the frontiers of science on a competitive international basis. In contrast, applied research has very definite practical objectives. It can and should be a highly creative process involving originality, imagination and inventiveness. In a desirable situation, these qualities, in the case of applied research, should be of the same magnitude as for basic research. It is not the degree of creativity that distinguishes basic from applied research but the clear practical direction that applied research aims at. In contrast, design and development relates to the effective and economical execution of a task that has been shown to be feasible on the basis of applied research and past experience.

Another important aspect of fundamental research is its essential place in the system of education. In its broadest sense, education involves the totality of effort related to acquiring new knowledge, preserving it in suitable form, and transmitting it to future generations, together with the thought processes involved. Very often, with obvious unfortunate consequences, the mere process of handing over knowledge as a dead, inanimate object is considered to be education; this happens in many of the educational institutions in India that stress uniformity and learning by rote. The only way in which teaching

can be brought out of this rut of routine, pedantic transmission of facts is by ensuring the accomplishment of significant research that leads to a tradition of penetrating and independent inquiry. Such research may be pure or applied, but must be of high quality and encourage innovativeness.

Education is primarily the responsibility of the universities, and quite clearly there must be basic research at the universities if education has to have any quality. The question, however, can be asked whether all the basic research that needs to be done can be done within the universities; and I believe, the answer to that question will be in the negative in today's context. The reason is that a lot of basic research today involves rather large expenditures, major facilities and infrastructural support, close links with technology and interdisciplinary efforts. This could involve accelerators, telescopes, major facilities for biological research and so on. These are best located and managed in separate research institutions, which will need autonomy and a culture necessary for them to manage large technical facilities and conduct interdisciplinary programmes. However, in my view, such institutions could be within, or should be colocated with educational institutions, so that the research institution participates in the university activities and vice versa.

We must recognise that different kinds of institutions are appropriate for various categories of activities, and what is important is to establish associations and linkages between them for mutual benefit. For example, a university associated with a government or industrial laboratory may acquire thereby the stimulation of constant contact with applied problems and also have available to it the large scale facilities that are necessary and have been developed for applied research. Correspondingly, the government or industrial laboratory acquires increased contact with the very talented enthusiastic young students and the openness of the university environment. What is required in such a linkage is not purely in terms of financing of research in the university by the government or industrial laboratory, but mutuality in participation. Mutuality cannot come about in wholly unequal relationships. It is for this reason that the weakening of our university research capabilities, through lack of support, is reducing the possibilities of such mutually highly beneficial linkages.

I can now particularize the scenario to the national plane. We have a large number of universities throughout the country. In their vicinity there are major research institutions coming under the purview of the Atomic Energy and Space Commissions, the Council of Scientific and Industrial Research, the Defence Research and Development Organization, the Indian

Council of Medical Research, Indian Council of Agricultural Research and Department of Science and Technology, the various surveys such as Survey of India, Geological Survey of India, Botanical Survey of India, Zoological Survey of India, as also major industrial units, some with excellent R&D facilities. There is, however, very little that is being done to establish strong interconnections between the University system and this infrastructure. There are a variety of schemes that I can think of which can be used for this purpose. The most classical is the use of university staff as consultants by industry and national institutions. This must be made compulsory. Such consultancy provides the academic community with opportunities to get acquainted with important industrial research problems which challenge the scientific imagination. The consultants can be used for probing areas that are new and unfamiliar to the company or laboratory, as well as for giving lectures to the staff. (It is, in fact, my experience that very few lectures are given in most government or industrial research laboratories, which is a pity, since science thrives and grows only through open, critical discussions.) Through these interactions the academic community can be exposed to the industrial environment, its problems and its attitudes. Conversely, it is important to provide visiting professorships, adjunct professorships, participation in university activities through advisory committee etc. to those from industrial and other national institutions. These provide opportunities for scientists from governmental or industrial laboratories to keep in touch with a broad spectrum of intellectual activity that a university represents and to widen their horizons.

There are a variety of such mechanisms to bring about better linkages that could be of mutual benefit; I have just indicated a few possibilities. Whilst some forms of collaboration have been worked out, it is nowhere near what can be achieved.

To my friends in the scientific community I would like to emphasize the point that basic research does not mean any research that is carried out which does not qualify as applied research. Basic research is characterized by high quality and innovation. It is subject to a system of peer review, and must arise from a deep inner urge to find out. It must, in the ultimate, be competitive at a truly international level. In this connection, I would like to recount a fable by Prof. Karl Popper: "Suppose that someone wished to give his whole life to science. Suppose that he therefore sat down, pencil in hand, and for the next twenty, thirty, forty years recorded in notebook after notebook everything that he could observe. He may be supposed to leave out nothing: today's humidity, the racing results, the level of cosmic radiation and the stock market prices and the look of mars, all would be there. He would have compiled the

most careful record of nature that has ever been made; and, dying in the calm certainty of a life well spent, he would of course leave his notebooks to the Royal Society. Would the Royal Society thank him for the treasure of a lifetime of observation? It would not. The Royal Society would treat his notebooks exactly as the English bishops have treated Joanna Southcott's box. It would refuse to open them at all, because it would know, without looking, that the notebooks contain only a jumble of disorderly and meaningless items." The reason is that as Paul Weiss has said: "The primary aim of research must not just be more facts and more facts, but more facts of strategic value".

I must confess that there is a considerable amount of so-called basic research done in this country, which falls in the category of that described in Karl Popper's fable; very large numbers of Ph.D's seem to emerge from our education system on this basis; reputations have been built up through the publication of hundreds of papers only to fool the untutored. All that is done is mere data collection on a routine basis, without any urge whatsoever to really understand something new about nature. This is not to decry data gathering, because it is no doubt useful and necessary, for it is only on the basis of data that one can build up models, hypotheses, theories and so on. However, it is necessary that the data gathering process be treated as a means in an innovative manner, and must relate to analytical and interpretative research. It must be motivated by a deep desire to know.

NEED FOR CENTRES AND SCHOOLS OF EXCELLENCE

It is quite clear that basic research is carried out by, and around, gifted individuals. This is true of any creative human enterprise such as music, art, dance and so on. It is well known that, apart from the innate gifts that an individual may possess, there is a very important component which an individual derives from the environment, particularly that close to him, and more particularly from a gifted teacher. It is this concept which has been the basis of the "guru-shishya" relationship in Indian education, and of the great "gharanas" of our country in music and dance. One can, in our country and abroad, trace great accomplishments and individuals to great schools, and establish a genealogy based on teacher-pupil links. This is certainly true of science.

In the autobiographies of great scientists, one repeatedly comes across phrases which trace their own achievements to the influence of outstanding teachers. For example, Liebig was a pupil of the great French chemist Gay-Lussac, the discoverer of some of the fundamental laws of the behaviour of gases, and Gay-Lussac was in turn a pupil of Berthollet. Liebig has remarked

"The course of my whole life was determined by the fact that Gay-Lussac accepted me in his laboratory as a collaborator and pupil". Liebig, in turn told his student Kekule, who later became famous for his contribution to the structure of organic compounds, specially the ring structure of benzene: "If you wish to be a Chemist, you must be willing to work so hard as to ruin your health". This was to emphasize the importance of hard work as a prime element in science. From Liebig one can trace several successive generations of scientists, containing more than 60 exceptionally distinguished names, and including more than 30 Nobel Laureates. The Deutsches Museum in Munich gives the genealogy of 17 Nobel Laureates who were members of a teacher-pupil family descended from Von Baeyer. One of these was Otto Warburg who has remarked "the most important event in the career of a young scientist is the personal contact with the great scientists of his time. Such an event happened to me in my life when Emil Fisher accepted me, in 1903, as a co-worker in protein chemistry". Warburg's student was Hans Krebs who also won Nobel prize and has remarked "If I ask myself how it came about that one day I found myself in Stockholm, I have not the slightest doubt that I owe this good fortune to the circumstance that I had an outstanding teacher at the critical stage of my scientific career. He set an example in the methods and qualities of first rate research". The essential point we have to keep in mind is that distinction develops if nurtured by distinction. It is attitude rather than knowledge which is conveyed by a distinguished teacher; as also enthusiasm which is the only basis on which exceptionally hard work that is ultimately required, does get put in. An important element of attitude that a great teacher imparts is that of humility, and from it flows a self-critical mind and the continuous effort to learn and to improve. One can trace in the history of science great schools and centres as at Paris, Göttingen, Cambridge, Oxford, Berkeley and so on.

It is of course true that there are many individuals who are prodigies or geniuses in their own right, and do not trace their links with any existing school. In India, scientists like Srinivasa Ramanujan, C.V. Raman, J.C. Bose fall in this category. However, such an individual, given the right opportunities, will very often be the starting point of a genealogy of excellence. One can trace many of the first rate scientists in India to schools nucleated by C.V. Raman, Meghnad Saha, S.N. Mitra, Homi Bhabha and so on. However, it takes time and an appropriate environment with long-range support, to ensure full flowering of any such school. Unfortunately, in India, what should have been points from which whole generations of excellence came forth, dried up too early. Homi Bhabha has remarked "It is the duty of people like us to stay in our own country and build up outstanding schools of research such as some other countries are fortunate to possess." His other phrases, in this

connection, were: "Build up in time an intellectual atmosphere approaching what we knew in Cambridge and Paris"; and again would have an electrifying effect on the development of science in India".

It must be remembered that very often an individual by himself tends to get lost, unless one was dealing with a genius like Einstein or Dirac or in India Ramanujan. We have to recognize the importance of an overall supportive environment and of team work. Jacques Monod has commented in his Nobel lecture on the importance to him of a Rockefeller Fellowship which gave him an opportunity to work at the California Institute of Technology in the laboratory of the Nobel Laureate Morgan: "This was a revelation to me—a revelation of what a group of scientists could be like when engaged in creative activity, and sharing it in constant exchange of ideas, bold speculations and strong criticisms".

It is very clear that most human beings never stretch themselves to the limits of their abilities. It is the outstanding teacher who attracts the finest students; and, in the overall intellectual environment that the team represents, the individuals are pushed to the very limits of their intellectual capability, each deriving strength from the other in a resonant and supportive manner. It is this that we should aim at creating in the country. This, however, demands both the highest standards in selection and flexibility in management.

Under the banner of equality and democracy, circumstances operate powerfully against the development of excellence in science; very often I fear we have too much of equality and too little promotion of excellence. This is not a matter which is the responsibility of Government alone, though it also has some responsibility in terms of the rules and regulations that it frames for general administration and makes applicable uniformly to scientific activities. The primary responsibility is of the scientific community, which must recognize excellence as something precious, which requires the entire effort of the community to cultivate and nurture, and not something to be destroyed through envy and jealousy, and for the petty considerations of individuals and groups.

LOUIS PASTEUR: THE OPPORTUNITIES FOR BASIC RESEARCH IN THE IMMEDIATE ENVIRONMENT

I would like to spend a few minutes on what we could learn profitably from the life and work of a great scientist whose work I have always admired, since I have felt that it has so much relevance to our circumstances and for the choice of areas for research. The scientist I speak of is Louis Pasteur, who took his doctorate with dissertations in both physics and chemistry, and then carried

out an impressive series of investigations on the relation between optical activity, crystalline structure and chemical composition in organic compounds. His work opened the way to a consideration of the disposition of atoms in space, and his early memoirs constitute the founding documents of stereochemistry. From crystallography and structural chemistry, Pasteur moved to the controversial and inter-related topics of fermentation and spontaneous generation. These were then empirical areas like cooking is today, but converted to areas of science through the work of Pasteur. This came about because he was appointed Professor of Chemistry at the Faculty of Sciences at Lille, which was newly established with the objective of bringing science to the service of local industry. While resisting any emphasis on applied subjects at the expense of basic science, Pasteur strongly supported the goal of linking industry and the Faculty of Sciences. His work in the area of fermentation (traced to the brewing industry in Lille) was based on his earlier interest in optical activity. He promoted specific living microorganism, and was responsible for the sterilizing procedures called 'pasteurization'; he laid the foundation for the germ theory of disease, which was thereafter developed rapidly by others notably Joseph Łister. For a period of almost 30 years he worked in succession on silkworm diseases, where he achieved remarkable success, and on the etiology and prophylaxis of a range of infectious diseases, anthrax, fowl cholera, swine erysipelas and rabies. He developed one treatment directly applicable to a human disease, namely for rabies. It is interesting that all of these problems that Pasteur encountered were in his immediate vicinity and interest in them evolved from his own basic research in which he displayed great experimental ingenuity. His approach was fundamental and resulted in the formulation of new biological principles. We have only to look at the range of problems that we encounter in our environment, whether in the area of population, communicable diseases, agricultural production, meteorology, energy, and so on to realize that there are challenges to excite the keenest minds in our vicinity and in our surroundings. To meet these challenges one would have to devise new techniques, new instruments, new insights and approaches which could as easily open a window into the hitherto unknown areas of nature, leading to work at the frontiers of science and contributing to the world pool of knowledge, without necessarily being dictated by fashions set elsewhere in the world. And there are areas of pure science such as astronomy in which we possess locational advantages where work of the highest order is possible with relatively small investment. This is true of mathematical and theoretical areas.

ILLUSTRATIVE AREAS OF THRUST

I would now like to cover, on a broad illustrative basis, certain areas of thrust in basic research which are of great interest scientifically, and where one

can also see very clearly, relevance in terms of possible tangible fruits in the not too distant future.

Let us look at the field of food production. The history of agriculture goes back over a period of many thousands of years, since man shifted from his role as a food gatherer to a cultivator. Farming could be successfully carried out in the rich and fertile river valleys such as those of the Euphrates and Tigris, the Changjiang and the Indus. Based on a certain amount of logic, experience and common sense, coupled with knowledge concerning the movement of the sun and stars which define the seasons and weather, and which could be regarded as rudimentary science, agriculture developed in a rather empirical fashion since its earliest days upto relatively recently. However, the situation radically altered over the past century to make agriculture a highly science-based area of production. Remarkable success has been achieved in increasing yields of many plant varieties, through an understanding of aspects of genetics and breeding, of nutrient requirements and of pest control. This success owes very significantly to the inputs that could be provided in the form of water and fertiliser which were available cheaply so long as energy was available cheaply. Whilst the production outputs grew significantly this has not been the case with production efficiency in terms of energy. India had a good base in the agricultural sciences when the process of modernization to increase yields in Indian agriculture was initiated around two decades ago, forced largely under the pressures of a large and growing population and the need to produce adequate food to avoid very heavy imports that would otherwise be needed, with consequent problems of both availability and high foreign exchange outflows. This modernization and increase in food production depended on an agricultural strategy similar to that adopted in the Western countries, which was essentially energy-intensive. This was an appropriate strategy at that time before the energy crisis of the 1970's. It was essential to tide over the immediate problem of raising food production to a level of self-sufficiency. It is on this basis that currently India has a production of around 135 million tonnes of foodgrains. India had no choice but to initiate the energy-intensive agricultural, so-called green, revolution. As the Prime Minister, Mrs. Gandhi, has stated:

> "It was a time of acute grain shortage, and the point was how do we immediately double the production of wheat. And so we went all out, and that is how we have been able to survive all this time, even through droughts".

This strategy and similar improvements in many crops such as rice, pulses, oilseeds, and many cash crops will and must continue, to enable us to meet the

immediate problems of demand and to avoid or reduce imports. The question, however, is what should be the strategy in the long run.

First and foremost there is the question of energy. Oil is still a significant item of import, and has been subject to several increases in price in recent past, making a total price increase of twentyfold over the last 8 years. Oil is a non-renewable source, and with expanding world population and industrialization, rising standards of living and human expectations, one must accept the fact that it will become more scarce with time and more expensive; and dependence on it in any major way can only make us vulnerable. It is, therefore, important to see whether agricultural strategies cannot be developed which will make lesser demands on chemical fertilisers which are oil-based, and lesser demand on energy for agricultural operations. In the short run we must certainly produce more fertiliser. Even though India today is the fourth largest producer and consumer of fertiliser nitrogen in the world, the country is faced with a gap which will increase to 4 million tonnes by the end of the Sixth Five Year Plan and to a much larger figure by the end of the century. The imports of large quantities of oil, food grains, edible oils and fertilisers can be supported in the short term through loans and have to take place to meet immediate needs. But what of the long-term? Consider the case of fertiliser. The question is whether we can turn to methods of providing nitrogen to plants without depending wholly on chemical fertilisers, where nitrogen is fixed through the intensive use of energy. We must remember that until recently our agriculture has survived for thousands of years depending on the renewable sources for nitrogen existing in our soil. Can we extend the host range of nitrogen fixing organisms and identify new bacteria and other microorganisms which will fix nitrogen? Can we transfer the nitrogen fixing genes to a wide range of microorganisms through the process of genetic engineering? These could then form symbiotic or non-symbiotic association with crop plants like cereals, in addition to the pulses. This immediately takes us into problems of genetic engineering, microbiology and soil sciences using nitrogen fixation concepts right at the frontiers of modern life sciences.

Another extremely important area of basic science from the viewpoint of agriculture, and of energy, is the area of photobiology. All biomass on the earth is produced through the process of photosynthesis, in which using the sun's energy, carbon dioxide and water can be converted to carbohydrate and oxygen; and additionally, nitrogen, sulphur and so on can be incorporated. The final efficiency of the process, when one considers large scale biomass production, tends to be only of the order of 0.02%. The question is: can we improve this efficiency? And this takes us into areas of "whole plant physiology and biochemistry". Further, a detailed study of the various

elements involved in photosynthesis might enable us to mimic some of the reactions artificially, so that one can photochemically produce hydrogen from water. It is expected that in time this will become an important source of energy.

Energy today has assumed very important dimensions from the viewpoint of both availability and cost. In India, half of the energy used is non-commercial energy, which means burning up of wood, agricultural residues and animal dung. This is leading to serious deforestation and desertification. Possibilities exist for improving the whole area of forestry through the techniques of tissue culture, nutrient inputs, genetic engineering and nitrogen fixation techniques, as discussed earlier in the case of crop plants. We can also consider production of varieties like sugarcane and tapioca, which make extremely good use of the sun's energy, and these could then be converted to produce ethanol which is a basic chemical building block.

We are aware of the problems of diseases in plants, and that these are larger by a factor of ten in the tropics compared to the temperate zone. Pesticides are being used but have their own problems relating to the environment and health. Strategies relating to integrated pest management are called for and these will involve work in insect physiology at the frontiers of our present knowledge.

There is no question that the success of the green revolution owes significantly to the farmers and peasants who were responsible to recognizing the potential of the new strategies and implementing these with success. However, it is important to point out that the so-called green revolution could never have come about but for the scientific discoveries and scientific data accumulated over the period of time prior to the breakthrough. As I have already mentioned these strategies will and must continue; and there will be many aspects of research that will need to be conducted in the agricultural institutes and universities which will relate to practical aspects to meet the felt needs of the farmer. But these by themselves are not going to solve the complex problems that we are going to encounter in our Seventh Plan and beyond. To solve these problems we need new approaches.

There was a symposium on "Basic Sciences and Agriculture" organized under the auspices of the Indian National Science Academy in 1975. The proceedings of this Symposium bring out in great detail the variety of possibilities for new quantum jumps in productivity in the field of agriculture. These possibilities are based on basic research in varied fields such as plant physiology and photosynthesis, biological nitrogen fixation, new work in

genetics and genetic engineering and so on. New institutions, centres and programmes need to be supported in these areas; and the potential rewards from this basic research are likely to be so great that we must go ahead even at the risk of failure. But whilst such symposia are held, and valuable and feasible recommendations are made, the follow-up tends to be not commensurate with the importance and urgency of the problems. In my view, this is the opportune time when we should be thinking and planning for the new agriculture that we require in a decade from now and undertake the basic researches that will enable this to happen.

In recent decades we have been witnessing a major revolution in the field of life sciences. This has primarily been brought about through an increased understanding of biological systems at the cellular and molecular levels. This would not be the place to go into the details of these spectacular changes that have come about in our understanding and in our capabilities. These capabilities, coming under the broad heading of biotechnologies, relate to the fields of tissue culture, developments in the field of recombinant DNA technology or genetic engineering, plasmid and gene transfers, developments relating to hybridomas and aspects relating to enzyme engineering, immunology, photosynthesis etc. Apart from the fact that these are areas of science where there is great excitement and significant new developments are taking place continuously, it also turns out that these are areas with great practical application.

We are now aware of the formation of companies based on biotechnologies, originally started by life scientists who had developed and worked out these techniques, and now significantly backed by major oil companies and pharmaceutical and chemical companies; these new companies are in the several hundred million dollar category. The beneficiary areas are those of agriculture, medicine, energy and industry. For example, in agriculture one is considering the possibility of genetically changing plants to give them resistance to pests, drought and saline soils; to make them convert sunlight more efficiently; and to persuade them to fix nitrogen from the air rather than relying on expensive fertilisers. Even without going as far as genetic engineering, considerable developments are taking place through conventional plant breeding and protoplast fusion. In forestry, there are new efforts relating to large scale propagation of trees from cells taken from leaves and growing baby trees in test tubes. Biological processes are being developed for a whole range of chemicals such as ethanol, ethylene glycol, ethylene oxide, lubricants, olefins and paraffins, various fine and ultra-pure chemicals etc. In the area of medicine many products are likely to be extracted from blood by genetic engineering including albumin, urokinase etc.; and this technique may

be used to produce a number of vaccines such as those for animals for swine dysentery, and safer foot-and-mouth vaccine; and vaccines for human use against hepatitis and possibly malaria. Hormones such as human growth hormone (HGH) and insulin which control various activities in different tissues of the body, and interferon which is part of the body's immune system, are all products being worked on for production through genetic engineering techniques.

It is clear that with the range of problems that we have in the areas of agriculture, animal and human health, population control, energy and the production of a range of interesting chemicals and pharmaceutical products, the new biotechnologies will play an increasingly important role. These technologies are science-based, and if one is going to embark on them and to participate in their development, particularly for applications of great interest to our country, we will have to encourage and support significantly research and development in educational institutions which alone can generate the needed scientific manpower, as also in major national institutions of research which will need to be set up where major facilities for work in such areas can be well provided.

I shall now cover briefly some areas of basic science that are relevant to high technologies. There is today, a large gap between basic science and engineering in our country. We have to recognize that with regard to areas of high technology, our industry is behind that of the advanced countries by at least a decade in terms of sophistication. In the advanced countries, sophisticated industries operating in the areas of high technology are able to interact rapidly with research scientists working in their fields in educational institutions and various research laboratories to make rapid use of the discoveries that are taking place. What are these areas of high technology? They are primarily the areas of: lasers; cryogenics (up to liquid helium temperatures); micro-technologies going down sub-micron levels; high temperature technologies; high pressure technologies; electro-optics and opto-electronics; new materials and so on. It is important to recognize that in all these technologies the innovative capabilities relating to work in science at the frontiers are required. If one does not have ongoing basic research to cover these areas, it would be very difficult even to identify meaningful areas of application, to define what can be indigenously developed and that which needs to or could be imported, and ensure systems engineering in the country. One can, for specific applications, certainly import equipment and systems for use as black boxes, or make some of these under licence in the country. But the rate of change in these areas is so significant that one will be permanently trailing, in cost and economics of production, and in international

competitiveness, in many areas where we have advantages otherwise. These also happen to be areas on which a very large number of Indian scientists and technologists are working abroad and it is unlikely that one can bring them back except through opportunities for similar work in India.

In more concrete terms let me illustrate the scenario in the fields of electronics and material sciences:

In electronics particularly since the Second World War, a continuing revolution has been taking place, the origin of which was basic scientific research relating to the applications of quantum mechanics to understand solid state phenomena. This resulted in the invention of the transistor, and thereafter through a series of integrated circuits to the very large scale integrated circuits in common use today where one talks of 256,000 bit memory chips, and achieving by the end of the decade million bit memory chips.

What is clear is that many apparently separate fields are merging together to form an enormously new and powerful whole. Advances in computer and communication technology are bringing about an inseparable union of these two fields. The development of these technologies is now mutually dependent. Large volume data to and from computers are transmitted over communication lines. Equally, telecommunication systems are becoming increasingly electronic with the introduction of electronic switching systems; it is the switching side which had remained largely mechanical and electro-mechanical up to now. In addition, a new development of great importance for high density traffic will be the use of optical fibre based telecommunication, where the light source will be a solid state laser. A further important development is that the communication format will become mostly digital. The shift from analog to digital systems will further merge the computer and communication fields.

The electronic revolution is bringing about an information revolution. Computers which were once considered to be large central machines meant primarily for large volume routine computation or for advanced research, are now becoming all-pervasive, with a continuous spectrum ranging from the pocket or hand-held calculator upto the largest computer. A major development has been the advent of the microprocessor. It is the evolution of the silicon chip technology that has enabled this progress in capability, lowered cost and increased areas of application; and as this chip technology continues to evolve, the distinction between micro, mini and large computers will depend less on size and storage capacity, and more on how they are used.

Computer cost and size have diminished over the years while computation speed has increased substantially; further increases in speed are expected. Computers now under development will store much greater amounts of information at less than one per cent of current costs. One of the major areas to work over the future will relate to software. As a result of all these, the information revolution will permeate society on a very general basis.

Information is the key to development and progress. Until recently transfer of information had been effected mechanically through persons, through mail and printed matter; and communication systems were largely mechanical or electro-mechanical. These involved bulk transport of matter; and mobility in physical space obviously had its limitations. In the future, information transfer will essentially be through electrons or coded electromagnetic waves. What will be needed are appropriate terminal devices at the points from where information is sent out and where it is received.

Apart from the aspects that I have already mentioned, major advances have taken place in microwave technology, radars, lasers, video systems and broadcasting, transducers, industrial control, inertial guidance and many other areas in electronics.

Let us now consider the area of materials. In the past we were content with making use of materials that were readily available. Present industrial needs demand new materials, with specific properties; this is particularly true for the high technology areas such as aerospace, nuclear and electronics engineering etc. The availability of suitable materials will define the progress possible in these fields. Factors that have to be taken into account are restricted availability and increasing costs of energy, as well as of many relatively scarce non-renewable resources.

In the area of discovery and extraction of raw materials, the new developments will be based on increased scientific knowledge about the earth, particularly based on the theory of plate tectonics, new systems for airborne profiling of the terrain, new technology in marine geology and geophysics to explore the ocean potentials (for gas, oil, minerals) particularly in the continental margins, and the use of remote-sensing techniques.

A substantial effort is needed to develop substitute materials, such as high strength polymers and ceramics in place of energy-intensive or scarce materials. Similar substitution efforts will cover replacement of stainless steel by iron-aluminium alloys, or whole platinum by platinum-coated parts; use of recycled material in asphalt pavements etc. Composite materials are often stronger, lighter and more durable than conventional materials, and their use

can lead to significant savings; examples are of fibre reinforced plastics, carbon fibre which is stronger than steel, and ferroics with 3-dimensional or 2-dimensional connectivities; in the case of these new materials, aspects relating to their life and of failure (under stress and environmental conditions) need careful investigation. In view of the problems relating to the high cost and decreasing availability of oil-based raw materials, possibilities need to be explored of organic materials extracted from plants, and particularly those that grow well on poor lands. In many cases, instead of new classes of alloys, material scientists hope to meet specific requirements by modifying the internal structures in metals through precise control of the steps in fabrication. Thus high-strength micro alloy steels may be increasingly used in automobiles because they save weight. It is now known that all materials can be made amorphous. Amorphous materials have unique properties (distinct from those of crystalline materials), and these properties can be exploited to advantage; examples are the use of amorphous semiconductors such as silicon, and of metallic glasses, that will find important applications for transformer windings etc. Mention should be made of the challenges in the area of superconducting materials, particularly the possibility of high temperature superconductors. Diamond is the hardest metal known; can we develop super-hard materials? Other possibilities in the field of materials include: synthetic polymers (plastics and synthetic rubber); low cost polymer materials with improved properties; ceramics, particularly silicon ceramics; materials based on directional solidification; powder metallurgy techniques to get near-net shapes; new methods for detecting wear; and new surface treatments particularly using laser and electron beams. This is only an illustrative list, but indicative of a high tempo of development that will continue to yield materials of interest for transportation, aerospace, electronics and other high technology applications. But these are areas that can be developed only through an understanding of the physics and chemistry of condensed matter, and the most advanced multifaceted instrumentation to probe compositions, structures, surfaces and so on.

In this part of my talk I have attempted to give both the philosophy as well as details of some fields which could be regarded as areas of thrust in agriculture, biotechnology, and in high technology areas such as electronics and materials. It would be a very elaborate exercise to do this in detail to cover all areas of science; and I shall, therefore, not attempt this in this talk. I would like to stress that my list is illustrative and not comprehensive.

SELECTION OF AREAS OF THRUST

It would be of some interest to consider the rationale that one could employ for selecting areas of thrust for basic research. Firstly, the area must be

one which is clearly regarded as in the front line of development, or likely to be so. It must be an area where one can build an effort which is viable and critical on the basis of resources that can be provided by a country such as ours. It should also be an area where there already exist interested individuals who are deeply motivated and of the highest quality, whose work should be supported and strengthened; it is always necessary to ensure a minimum size for research groups so that advantage can be taken of a high level interactive community; it is also desirable to have several groups working in the field in the country, who could interact amongst each other by exchange of personnel, through discussions, and for whom major and expensive facilities can be provided on a common basis. Finally, it would be desirable if the concerned area has clear possibilities for relevant application, that would be supported by other work in complementary areas of applied research and development, where larger sums of money are generally available for infrastructural aspects. In the absence of such criteria, the tendency is to look at each project or programme on its own merits, as it is put forward, and to spread the available resources over a wide range of projects that get approved, without leading to a critical mass or thrust in any particular set of areas. It is the responsibility of the scientific community to discuss these issues and put forward its views on how the scientific effort should be focussed so as to make the greatest impact at a select number of points across the whole scientific front. It is, of course, clear that resources must be available for the support of individuals of the highest quality, who may wish to put forward programmes of their own, which do not come within any such planning exercises. The system must have the capacity to recognize such situations, and the flexibility to ensure that such support is provided.

It is worthwhile to emphasize that there have been spectacular advances in the field of instrumentation that have transformed the entire experimental approach in science. The days have gone when scientists had to take readings, record them and make graphs etc. using the data. Today, practically every instrument is a "smart" instrument with attached microprocessors which enable the data to be automatically reduced to desired formats and then display or print them. Interactive displays are also in use in a variety of situations. There are a whole host of new techniques for analysis of minute quantities of materials at the levels of parts per billion or parts per trillion impurities in solids. We can look at atoms directly with high voltage high resolution electron microscopy, under realistic conditions including dynamic changes. A variety of techniques can be brought to bear simultaneously on a single problem giving insights from different angles. A laboratory equipped with these modern instrumentation facilities is capable of obtaining data of a highly complex nature and proceeding then to the building up of hypotheses

to enable further planning of experiments, all in a matter of a few hours or a few days, whereas working with the older approaches that many of us used two or three decades ago, and that are available in our laboratories, one would need time periods of half-a-year or a year for this. It is extremely important that instrumentation facilities right at the front line be provided on a selected basis in the country.

ROLE OF THE PROFESSIONAL BODIES SUCH AS THE ACADEMIES AND INDIAN SCIENCE CONGRESS IN FOSTERING BASIC RESEARCH

Scientific academies, professional societies and those concerned with the publication of scientific and technical journals have an exceedingly important role to play in setting standards of excellence for scientific research. This is primarily because science can only advance through open critical discussion and debate. Scientific work must be presented to the widest possible audience. Indeed in the earlier period, scientists made serious efforts to communicate with each other by extensive correspondence so as to get different views to bear on their own work and thinking. Today, this is largely accomplished through meetings and publication of scientific results in journals. It is not surprising that the tremendous growth of science that has taken place over the past few hundred years is also related to the advent of printing and the increased ability to travel and interact. A principal objective of scientific academies and professional societies/institutions should be to arrange for such scientific discussions. Indeed, in all scientific institutions, there must be a conscious effort to have regular programmes of lectures, seminars and discussions, where the work being carried out is presented and critically assessed. Science does not believe in secrecy. Science also does not believe in hierarchy and the youngest listener has the fullest right to question and criticize what may have been put forward by senior and distinguished scientists. Indeed, this must be encouraged, for it is more than likely that the younger colleague has the more original approach, whereas it is the more senior scientist who has greater experience, information and skills. In the case of papers sent to scientific journals they ought to be objectively and critically refereed so that only sound work gets published. In the absence of good journals of science in the country, the tendency is to publish abroad; this has in any case been so because of the undue importance attached within the country to publications in journals abroad. The scientific and professional societies of the country must come together to ensure that the major part of the scientific work done in India, and certainly the best work, is published in this country. Professor Raman has remarked: "While the foundation of the scientific reputation of a country is established by the quality of work produced in its institutions, the superstructure is reared by the national journals which proclaim their best achievements to the rest of the world. Manifestly the

edifice of science in India is incomplete... It is true that the spirit of science and its service are international, but it is not also true that every nation has its own Academies, learned societies, magazines and journals? India will have to organize and develop her national scientific institutions before she can enter into the comity of international scientists."

It is for this reason that a special effort is being made during the Sixth Plan period to consolidate and strengthen the professional academies and societies in India to play this role.

On this occasion, let me say something more particular about the Indian Science Congress.

The Indian Science Congress was established in 1914 with the first objective being defined as "to advance and promote the cause of science in India". In fact, in the detailed account relating to the Indian Science Congress Association it is stated that it was "Established in 1914 to convince people and Government that science plays a vital role in the life of the nation". It is very clear from these objectives and the manner in which the Indian Science Congress is structured, that it is largely patterned on the British Association for the Advancement of Science which had its first meeting in York 150 years ago. It may be of some interest for those of us concerned with the Indian Science Congress to go back to the origins of the British Association which can be traced back to Charles Babbage, credited as the father of the computer, and to David Brewster, the well known optical physicist and the inventor of the kaleidoscope. I recount this background intentionally for the reason that it throws light on the manner in which science has changed with time and also on how we should organize ourselves in the future to promote the cause of science.

Babbage who was on a visit to Germany in 1827, at the invitation of the great Alexander Von Humboldt attended a meeting in Berlin of the Deutscher Naturforscher Versammlung. This society had arisen from the idea of having "a great yearly meeting of the cultivators of natural science and medicine from all parts of the German fatherland". Babbage was greatly impressed by the meeting. At that time he was, in fact, very depressed about the state of science in his country, and had written a book entitled "Reflection on the Decline of Science in England". On return from Germany, Babbage wrote an article in the Edinburgh Journal of Science, edited by David Brewster, on the German meeting which he had just attended. This struck a sympathetic chord amongst many in Britain. Brewster worked up the idea of having such a meeting in Britain and what it could do. He stated that it would make: "the cultivators of

science acquainted with each other, to stimulate one another to new exertions—to bring the objects of science more before the public eye and to take measures for advancing its interests and accelerating its progress" and further "to revive science from its decline, and the scientific arts from their depression; to instruct the government when ignorant, and stimulate when supine; to organize more judiciously our scientific institutions, and the public boards to which scientific objects are entrusted, ... to raise scientific and literary men to their just place in society". These views would hold good as the objectives of the Indian Science Congress today.

I would also like to remind you that some of the great discoveries of science were reported originally at the British Association for the Advancement of Science. These included: J.J. Thomson's announcement of his discovery of the electron (1899); the demonstration by Crookes of the properties of Cathode rays (1879); the discovery of a new gas Argon by William Ramsay (1894); the ideas of James Joule on the mechanical equivalent of heat (1843); Clark Maxwell's first reports on molecular physics, and ideas on the Maxwell distribution (1873); Fitzgerald's report on the discovery by Hertz of the electromagnetic waves predicted by Maxwell (1888); Millikan's measurement of the unit charge on the electron (1909); etc. Additionally, many of our scientific units originated with the British Association: the joule; the ohm, the dyne and the erg; the CGS system of measurement etc. I am more than aware that all this occurred in the historical days, just when science started on its present dizzy exponential growth. Today most discoveries are reported over the radio and in the daily press, and discussed at highly specialized thematic meetings. They are no longer reported at the British Association for Advancement of Science, nor will they be at the Indian Science Congress. (We should of course remind ourselves that Prof. Raman reported at the January 1929 (Madras) Science Congress, in his Presidential Address, the work done in Calcutta over the previous year which resulted in the discovery of the Raman Effect.)

There is no reason, however, why topics of major scientific interest and excitement should not form part of our discussion at the Indian Science Congress which happens to be the largest single gathering of scientists in the country, covering the whole range of sciences. The Indian Science Congress should not be a place for reporting of routine measurements or for discussing pedestrian details of science policy. It should be a forum to generate a sense of enthusiasm and elan in the scientific community. With its coverage of a wide spectrum of scientific disciplines it can arrange for panel discussions on interdisciplinary aspects where some of the major thrusts occur for as C.V. Raman has remarked: "History of science has shown that real fundamental

progress is always due to those who had ignored the boundaries of science and who treated science as a whole". This was a man interested in the colour of the sky and of the sea, in crystals and diamonds, in the theory of vision and of hearing; in the theory of musical instruments and much else.

Basic research always happens to be an area of innovation, originality and excitement. And the Science Congress should attempt to focus in this direction if it is to be dynamic and relevant and excite the young minds.

An aspect which the scientific community must always keep in mind is that, if science is to grow and flourish, it must attract to science some of the finest minds of the country. This can happen if one can convey to the potential young scientists a sense of excitement and the possibility of new discoveries. It is the young minds who are characterized by the greatest originality, and it is this generation which is capable of putting in exceptionally hard work. A very important reason for strong support to research in the educational system is that it is here that we find the truly young generation, in the student community. Some deliberate measures are called for to see that the best and well trained amongst them are provided adequate incentives to take up research as a career, and that areas are defined and supported that best serve national interests and priorities towards which such talent can be directed or encouraged to work on. The Indian National Science Academy awards each year the Young Scientists Medal, which is presented by the Prime Minister at the Indian Science Congress Session. This is an attempt to focus attention on work of high quality accomplished by very young Indian scientists. Particular efforts are also being made in the Sixth Plan to involve young scientists directly on a more active basis in scientific research and development.

CONCLUDING REMARKS

In conclusion, I would like to restate some of the aspects that I have covered in this address that I regard as important, and also which call for action both on the part of the scientific community as well as decision makers at various levels.

Indian science and technology have been placed on a relatively firm footing through major efforts since Independence. We are now at a take-off point, but the question is whether we will seize this opportunity. A large part of the resources allocated have been in the areas of applied research and development, and in these, wherever clearcut tasks have been assigned, Indian science and technology has invariably produced the results expected of it. What is important is that, on the basis of perspective planning, the needs and

investments in the productive sector are clearly defined, well in advance, so that the appropriate scientific effort can be initiated right now to meet those requirements. Furthermore, there is no point in undertaking applied research and development on an ad hoc basis, without a clear appreciation that investments will take place downstream which can make use of the scientific effort.

The world of today is quite clearly a world characterized by science and technology. In the future it will be characterized even more so. Technologies relating to areas across a whole spectrum of agriculture, health, energy, industry and so on are becoming increasingly science-based, and for any meaningful efforts in applied research and development it is essential that we have in the country the appropriate background of basic understanding. This, as well as its role in the system of education and the creation of manpower in the country with innovative capabilities, demands the execution of basic research across a wide spectrum. Applied sciences and technology are forced to adjust themselves to the highest intellectual standards that are developed in the basic sciences. This influence works in many ways: for example, some students trained in basic research come into industry; again, the techniques which are developed and applied to meet the most stringent requirements of basic research at the frontiers of human capability serve to create new technological methods for industry.

There is total national agreement on the importance of self-reliance. The problems we encounter are large in magnitude, and many are locale specific; we have to find solutions for these ourselves, and it is for this that innovative thinking, characteristic of basic research, acts as a pace setter. All of this is inherent in the Scientific Policy Resolution. What we need to do is to aim steadfastly at implementing this Resolution in its true spirit.

Basic research needs to be supported first in the educational institutions which have been allowed to run down sadly in recent years. Much greater support is required to build up the infrastructural capabilities, at least on a selected basis, in educational institutions. Apart from this, basic research must form an integral part of other research bodies. In many areas of agricultural, industrial and defence research, faced with the problems of the immediate, there is a tendency for decision makers to insist that everything is directed at solving felt needs of the users. I have very often emphasized that in the case of the Council of Scientific and Industrial Research, the word 'scientific' precedes the word 'industrial'; and in fact the organization can be effective for industrial research only by carrying out scientific research. This is equally true in areas of agriculture, of medicine, of defence and so on.

We have to recognize that basic research has to comply with international standards of performance and excellence; and is centered around the most gifted individuals. The environment under which such individuals work, and attract outstanding pupils and create centres of excellence, is not the environment of factories or of Government departments. Apart from the financial support needed for nurturing such centres of excellence, there is the need to support them in generating the culture where such growth can take place. In this repsect, the situation has deteriorated in recent years.

Many of our activities today on the scientific scene relating to the educational sector, the national laboratories, the industrial sector and Government departments are largely compartmentalized. There is need for much greater linkages amongst these, which are not difficult to implement but are largely missing because of administrative and financial bottlenecks.

The future of science will depend on attracting some of the finest minds of the country to scientific research. The importance of enthusing and nurturing the potential young scientists of the country needs no emphasis. Professional bodies have an important role to play in this regard as also in that of popularization of science.

It is clear that resources both human and financial will not be available to cover the total spectrum of science and technology on a viable basis. We have to be selective in the thrust areas that we choose to concentrate on. Many of these can and will relate to problems in our immediate environment, which offer opportunities not only for work at the frontiers of science but also for work that could have relevance for large sectors of national development.

The value of basic research does not lie only in the discoveries it leads to which are international. There is more to it. It affects the whole intellectual life of a nation by determining its way of thinking, and the standards by which actions and intellectual production are judged; an atmosphere of creativity is established which penetrates every cultural frontier. It is fundamental research which sets the standards of modern scientific thought. As C.V. Raman has remarked: "Unless the real importance of pure science and its fundamental influence in the advancement of all knowledge are realized and acted upon, India cannot make headway in any direction and attain her place among the nations of the world. .... There is only one solution for India's economic problems and that is science and more science and still more science".

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Annexure

GOVERNMENT OF INDIA
SCIENTIFIC POLICY RESOLUTION

New Delhi, the 4th March, 1958

No. 131/CF/57. The key to national prosperity, apart from the spirit of the people, lies, in the modern age, in the effective combination of three factors, technology, raw materials and capital, of which the first is perhaps the most important, since the creation and adoption of new scientific techniques can, in fact, make up for a deficiency in natural resources, and reduce the demands on capital. But technology can only grow out of the study of science and its applications.

2 The dominating feature of the contemporary world is the intense cultivation of science on a large scale, and its application to meet a country's requirements. It is this, which, for the first time in man's history, has given to the common man in countries advanced in science, a standard of living and social and cultural amenities, which were once confined to a very small privileged minority of the population. Science has led to the growth and diffusion of culture to an extent never possible before. It has not only radically altered man's material environment, but, what is of still deeper significance, it has provided new tools of thought and has extended man's mental horizon. It has thus influenced even the basic values of life, and given to civilization a new vitality and a new dynamism.

3 It is only through the scientific approach and method and the use of scientific knowledge that reasonable material and cultural amenities and services can be provided for every member of the community, and it is out of a recognition of this possibility that the idea of a welfare state has grown. It is characteristic of the present world that the progress towards the practical realisation of a welfare state differs widely from country to country in direct relation to the extent of industrialisation and the effort and resources applied in the pursuit of science.

4 The wealth and prosperity of a nation depend on the effective utilisation of its human and material resources through industrialisation. The use of human material for industrialization demands its education in science and training in technical skills. Industry opens up possibilities of greater fulfilment for the individual. India's enormous resources of manpower can only become an asset in the modern world when trained and educated.

5 Science and technology can make up for deficiencies in raw materials by providing substitues, or, indeed, by providing skills which can be exported in return for raw materials. In industrialising a country, a heavy price has to be paid in importing science and technology in the form of plant and machinery, highly paid personnel and technical consultants. An early and large scale development of science and technology in the country could therefore greatly reduce the drain on capital during the early and critical stages of industrialisation.

6 Science has developed at an ever-increasing pace since the beginning of century, so that the gap between the advanced and backward countries has widened more and more. It is only by adopting the most vigorous measures and by putting forward our utmost effort into the development of science that we can bridge the gap. It is an inherent obligation of a great country like India with its traditions of scholarship and original thinking and its great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today.

7 The Government of India have accordingly decided that the aims of their scientific policy will be:

(i) to foster, promote and sustain, by all appropriate means, the cultivation of sciences, and scientific research in all its aspects—pure, applied and educational;
(ii) to ensure an adequate supply, within the country, of research scientists of the highest quality, and to recognise their work as an important component of the strength of the nation;
(iii) to encourage and initiate, with all possible speed, programmes for the training of scientific and technical personnel, on a scale adequate to fulfil the country's needs in science and education, agriculture and industry, and defence;
(iv) to ensure that the creative talent of men and women is encouraged and finds full scope in scientific activity;
(v) to encourage individual initiative for the acquisition and dissemination of knowledge, and for the discovery of new knowledge, in an atmosphere of academic freedom; and
(vi) in general, to secure for the people of the country all the benefits that can accrue from the acquisition and application of scientific knowledge.

The Government of India have decided to pursue and accomplish these aims by offering good conditions of service to scientists and according them an honoured position, by associating scientists with the formulation of policies, and by taking such other measures as may be deemed necessary from time to time.